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TRANSPLANTING ASPEN ON RECLAIMED COAL-MINE LAND USING DRIP IRRIGATION 2006 REPORT

Final

Transplanting Aspen on Reclaimed Coal-Mine Land Using Drip Irrigation

2006 Report

Research Agreement with Seneca Coal Company

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Introduction:

Quaking aspen (*Populus tremuloides*) is the most widespread tree species in North America (Baker 1925; Preston 1976; Lieffers and others 2001), and thought to be second in worldwide range only to Eurasian aspen (*Populus tremula*) (Jones 1985a). Aspen is found in most of eastern Canada and the U.S. (except the Southeast), throughout the upper Midwest and Lake States, across sub-boreal Canada and Alaska, in the Rocky Mountains from Canada through the U.S. and into northern Mexico, and in mountain ranges paralleling the west coast from Alaska through British Columbia, Washington, Oregon, California, and Mexico's northern Baja California (Preston 1976). The species is most abundant in the central provinces of Canada and in Colorado and Utah in the U.S. (Jones 1985a; Lieffers and others 2001). In much of the western U.S., aspen is a mid-elevation shade-intolerant species which is a relatively minor component of more widespread conifer forests.

Aspen is an important tree species throughout the western United States. One of the few broad-leaved hardwood trees in many western forests, it is a valuable ecological component of many landscapes, occurring in pure forests as well as growing in

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association with many conifer and other hardwood species. Aspen provide desirable scenic value, the diversity of plants growing under aspen supply critical wildlife habitat, valuable grazing resources, protect soils from erosion, and help maintain water quality. These features make aspen a crucial component of many Western landscapes.

At the continental scale, aspen has several physiological characteristics that permit it to attain great geographic amplitude. Lieffers and others (2001) outline the following important adaptive traits of aspen: 1) among the wide ranging genus *Populus spp.* (cottonwoods, poplars, aspen) aspen seems to have a very high stress tolerance. Usually high stress tolerance is associated with slow growing species and those with a limited reproduction strategy; 2) aspen appear to rely on vegetative reproduction via root suckering more than other *Populus* species. These authors assert that the passing of extensive root systems between generations enhances tolerance to absorb climate stress (DesRochers and Lieffers 2001); 3) Aspen also has the ability to adapt leaf size to xeric and mesic conditions (that is, smaller leaves for drier sites). Aspen's smaller leaf size could keep the leaf surface slightly cooler allowing earlier shut down of stomata, thus tempering water stress during drought; 4) aspen seem to tolerate cold temperature and short growing seasons better than most hardwoods (Pearson and Lawrence 1958); 5) leaf fluttering may be an adaptive advantage in cooling leaf surfaces of many *Populus* species and, 6) aspen appear to have a higher photosynthesis capability than other *Populus spp.* which is comparable to that of high yield poplar hybrids. Aspen photosynthesizes well in low light (for example, competitive situations) and even mature bark is capable of photosynthesis, which helps to ameliorate respiration during periods of high insolation (before spring leaf-out) (Pearson and Lawrence 1958). Photosynthesizing bark may help aspen recover from injuries and infestations (Jones and Schier 1985; Lieffers and others 2001) and may allow aspen to photosynthesize at low levels during the winter giving the tree a photosynthetic "boost" prior to leaf-out (Pearson and Lawrence 1958; Shepperd and others 2004). As leaf chlorophyll increases during the summer, bark chlorophyll decreases causing bark to become whiter (Strain 1964).

Although aspen does produce abundant crops of viable seed (McDonough 1979), it primarily reproduces vegetatively by root suckering throughout most of its

western range. Occasional seedlings do establish, but seedlings require bare mineral soil and constant moisture to survive (McDonough 1979). These conditions rarely occur in many of the areas where aspen grows today. Aspen typically grows in genetically-identical groups referred to as clones. All stems in a clone sprouted from the roots of parent trees and share a common ancestor. However they do not share a common root system, as connections break down from generation to generation as new trees grow new roots.

Most aspen stands are composed of one to several clones that may persist along a continuum of successional stages, from sparsely growing individuals to apparently stable pure or near-pure groves. Although clones are often separate and distinct from one another, studies have demonstrated spatial intermingling where multiple clones are co-located (DeByle 1964; Mitton and Grant 1980; Wyman and others 2003; Hipkins and Kitzmiller 2004).

Compared to conifers, aspen ramets – individual stems, or suckers, of the same genotype from a parent root system - are relatively short lived. This is due to succession (replacement of aspen by more shade tolerant species) and/or a typical onslaught of mortality related to stem decays and diseases from ages 80 to 100 years (Baker 1925; Hinds 1985; Potter 1998; Rogers 2002). Aspen thrive where somewhat regular and frequent disturbance promotes regeneration (DeByle and Winokur 1985). Occasionally aspen stands appear to perpetuate themselves with regular low-level regeneration in multi-layer stable stands (Mueggler 1988; Cryer and Murray 1992). Aspen in the western U.S. are longer lived than elsewhere. Healthy aspen trees can live over 300 years (Personal Comm., John Shaw, Forester, USDA Forest Service, Rocky Mountain Research Station) and can attain diameters up to 38 inches (96.5 cm) diameter at breast height (dbh), however most aspen are typically much younger and smaller. Many mature stands in Colorado are currently over 120 years of age (Shepperd 1990). Tree form varies from shrubby at upper and lower forest margins to over 100 ft (30.5 m) in height in prime locations with average heights of 50 to 60 ft (15 to 18 m) (Baker 1925).

Vegetative regeneration of aspen requires the interruption of the auxin/ cytokynin hormone balance between roots and shoots to stimulate root buds to begin growing (Schier et al. 1985). This hormonal imbalance can result from any disturbance that

interrupts the flow of auxin from photosynthesizing leaves to a tree's roots. This can result from disturbances that kill the parent trees outright, such as a fire, disease, and timber harvest, or from disturbances that only temporarily defoliate the parent tree, such as a late frost, defoliating insect attack, or light herbicide application. Severing lateral roots from parent trees can also initiate suckering, as would occur when fire, burrowing animals, or other factors kill portions of a lateral root. The sucker initiating process has been referred to as interruption of apical dominance (Schier et al. 1985).

In any case, the initiation of bud growth must also be accompanied by sufficient sunlight and warmer soil temperatures to allow the new suckers to thrive (Navratil 1991, Doucet 1989). Full sunlight to the forest floor best meets these requirements. However, young aspen suckers are susceptible to competition from other understory plants and herbivory from browsing ungulates, even if abundant suckers are present.

Having access to a well developed parental root system gives aspen sprouts a great advantage over other plants. The parent roots supply carbohydrates and access water deep in the soil profile allowing sprouts to grow rapidly, out-compete other vegetation, and withstand frequent droughty conditions in the West.

Re-establishing aspen on reclaimed surface-mined lands is therefore problematic, since the parent root systems are destroyed when topsoil is removed. Planting aspen in a non-irrigated location in a Colorado study was not successful (Shepperd and Mata 2005). Transplanting greenhouse or nursery-grown aspen seedlings into the field has similar problems to those of natural seedlings, indicating that the small root mass of transplanted seedlings is insufficient to absorb enough moisture to maintain the seedlings during periods of summer drought in the wild.

In contrast, transplanting sapling-sized aspen in irrigated urban landscapes has not been a problem, because the abundant supplies of water in lawns and landscape beds enable the transplants to thrive. Although aspen is somewhat tolerant of drought conditions (Lieffers et al. 2001), irrigation could benefit growth and survival of planted aspen stock, because moisture stress negatively affects aspen response to nutrient uptake (van den Driessche et al. 2003). Water deficit stress also reduces stomatal conductance, root hydraulic conductivity, and shoot leaf water potential in aspen

(Siemens and Zwiazek 2003). Irrigation has been shown to increase growth of hybrid poplar, a closely related species (Hansen 1988; Strong and Hansen 1991).

Therefore, it seems reasonable to conclude that supplemental irrigation of aspen planted on reclaimed surface-mined lands could increase initial survival and allow trees to grow sufficient root systems to ultimately survive without additional water and establish new self-regenerating clones on reclaimed mine lands. Testing this hypothesis, gaining additional knowledge about different planting methods, and documenting factors that potentially limit the re-establishment of aspen is crucial to re-establishing aspen on surface-mined lands in the arid west.

Another issue in transplanting aspen is tolerance of the species to saline soils. Saline condition of the reclaimed soils and/or irrigation water may be important in aspen growth and survival. Aspen has been listed as moderately sensitive (< 3.0 dS/m, Blaylock 1994), sensitive (upper limit EC of 2.0 dS/m, Pearson 2007), slightly tolerant (upper limit of 3 dS/m, USDA 2002), low tolerance (< 4 dS/m, Wentz 2001), or moderately high tolerance (up to 6 dS/m, Swift 2003) to saline conditions. Reclaimed lands that are saline are expected to have lower species richness (Purdy et al. 2005). They suggest that "facilitated colonization" is necessary for re-vegetation on saline overburden soils (Purdy et al. 2005). Van Cleve et al. (1993) found that high salt content of soil inhibited growth of aspen. Renault et al. (1998) report that aspen seedlings irrigated with saline water from mine tailings lost their leaves which were replaced by morphologically different leaves. These trees had increased leaf water potential and reduced transpiration. Saline conditions can cause lower water absorption by plants; and accumulation of salts in plant tissue can decrease leaf water potential (Renault et al. 1998). Knoxfield (1995) suggests that EC > 3.0 dS/m in irrigation water is unsafe, and EC > 1.5 dS/m of potting media is too high. Bauder et al. (2006) indicate that irrigation water with EC > 2.0 dS/m should not be used, particularly on soils with poor drainage.

A pilot study was established to examine the feasibility of using supplemental drip irrigation to establish aspen on reclaimed coal mine overburden soils. Overburden and topsoil are normally stored for a number of months before overburden is replaced and then resurfaced with topsoil, then landscape planted. The study described herein

examined growth and survival of aspen trees planted October 2004 on reclaimed soils. Half of the trees were planted on fresh roto-cleared soil moved directly to the site. The other half was planted on dozer-cleared soil that had been stored for a period of time. An additional treatment was added during the 2006 growing season to compare weeded vs non-weeded plots. This report provides information regarding growth and survival for 2006, the second growing season after planting. Aspen trees planted from potted nursery stock, and trees from natural sprouts on reclaimed soil were also examined.

Objectives:

The objective of this study initially was to examine the survival, growth, and water status of irrigated aspen transplants on roto-cleared and dozer-cleared topsoil placed over coal mine overburden material that had been replaced after surface mining. However, circumstances allowed us to expand the original study design to collect growth and survival data from: 1) aspen plants transplanted from a nearby mine, placed in dozer-cleared and roto-cleared topsoil within a fenced area and drip irrigated at three watering levels and an unwatered control; 2) unwatered sprouts arising naturally from aspen root segments that had been transported to the site in the two different soil types; 3) trees in plots weeded compared to those non-weeded; and 4) commercially grown potted aspen seedlings that were planted in a nearby fenced area.

Methods:

The initial project was a case study of the effectiveness of irrigation treatment on the survival, growth, and water status of aspen cuttings planted on a single site of reclaimed land of the Seneca Coal Company II-W mine south of Hayden, Colorado (Figure 1). The irrigated portion of the study was designed to measure the effect of supplemental irrigation on aspen saplings that had been transplanted on the II-W mine site from a naturally regenerating site on the Yoast mine where the original forest had been cleared in preparation for mining. Aspen saplings between 1-2 m in height were selected from this site at the end of the growing season in 2004 and pruned to leave only the uppermost branches intact. In October, 2004, these saplings were dug using a small backhoe and immediately transplanted into augered holes that had been prepared

at the fenced planting site at the II-W mine. All cuttings were presumed to be from the same genetic clone since they were collected from the same area. Trees were planted in eight blocks consisting of five rows of ten trees, (50 trees total) spaced on a 1.5 m x 1.5 m grid (Figure 2).

Soils used in the study were 1) Roto-cleared topsoil that had the original vegetation on the site chopped and mixed into the top 4 inches of topsoil prior to removal and replacement on the planting site; and 2) dozer cleared soils had all above-ground vegetation bladed aside for disposal prior to removal and replacement on the planting site. The dozer cleared soil used in this study had been stored for a few months, as indications of decay were present and fewer weeds grew in this soil. We refer to the roto-cleared soil in this report as 'fresh' soil and the dozer-cleared soils as 'stored' soil. Both soil types were from aspen stands, contained aspen roots and were placed to a depth of approximately 1 m on the planting site. The soils were spread by scraper in the late summer of 2003, and were final graded in May/June of 2004, prior to aspen planting in October, 2004. Four blocks of 50 aspen trees each were transplanted in each topsoil type.

Water was delivered during the 2005 and 2006 growing seasons by drip irrigation to the transplanted aspen saplings via a computer-controlled system that timed the daily application of water through calibrated emitters. The four water treatments (high, medium, low, non-irrigated control) were randomly assigned to one of the four blocks in each of the two soil types, with all 50 trees in each block receiving the same amount of water (Figure 2). Trees were watered using a gravity fed drip system, supplied by a 2000 gallon tank located more than 200 vertical feet upslope from the test site that provided an adequate head to maintain water pressure greater than 60 lbs. The water tank was filled by Seneca Coal Company workers as needed, generally once or twice a week.

Source of irrigation water during 2005 and for most of the 2006 season (July – Sept) was Sedimentation Pond 006 located lower in the reclaimed watershed. During the 2005 growing season drippers delivered water at 1 gallon/minute, and were programmed to deliver water daily at 1.3, 0.6, and 0.3 gal/day/tree for the high, medium, and low irrigation levels; equivalent to 14.4, 7.2, and 3.6 inches of precipitation per

month. The non-irrigated control received no supplemental water. Since there was little or no treatment difference due to irrigation level during 2005, perhaps due to the high levels of rainfall throughout that growing season, treatment levels during 2006 were reduced in half to 0.65, 0.3, and 0.15 gal/day/tree for the high, medium, and low irrigation levels, equivalent to 7.2, 3.6, and 1.8 inches of precipitation per month. Irrigation treatments were applied daily during the early morning, from June 9, 2006 to October 4, 2006. Drippers required 4 lbs pressure for activation. The valve box and distribution lines were configured so that head pressure down stream of the valves did not exceed this value to avoid leakage between irrigation treatments. Soil moisture and temperature sensors were located in each plot and data were recorded hourly. Because of the unreliability of the soil moisture sensors during 2005, gravimetric soil samples were collected periodically throughout the 2006 season from each irrigation treatment. Samples were sealed and transported to the lab where they were weighed, then dried and re-weighed for moisture content. Additional samples were collected from each irrigation treatment for chemical analysis. Soil chemical analysis and soil moisture were also conducted on soil samples collected from an undisturbed aspen stand about ½ km south of the experimental plot.

Standard meteorological conditions were monitored at an automated weather station located at the center of the plot, and data recorded hourly included wind speed, wind direction, air temperature, relative humidity, and precipitation. Hourly soil temperature, moisture content, and matrix potential were also monitored at one tree in each watering treatment. All data were recorded on a Campbell 23x data logger, which was also programmed to activate the irrigation solenoids. Power was supplied by 12 V batteries charged by a solar panel.

In addition to the transplanted aspen in the irrigation study, we also obtained growth and survival data from two other types of young aspen trees: 1) Natural sprouts that had grown from roots buried in un-irrigated areas of the roto-cleared and dozer-cleared soil adjacent to the irrigated blocks; and 2) commercially-grown potted aspen seedlings that were planted in an non-irrigated fenced area approx 1 km from the irrigation study site. It was not determined if the roots grew out of the potting mix into the surrounding soil during the first or second year of study. Lateral distribution of rooting

systems is necessary for aspen survival. A study has been funded by the Department of the Interior, Office of Surface Mining (DOI OSM) National Technology Transfer Team Applied Sciences Program, to complete this aspect of the study during the 2007 growing season.

For 2005, all aspen trees were weeded (2m weed-free area around each tree) to eliminate the effects of weed competition on aspen response to treatment. During the 2006 growing season a weeding treatment was added to the experiment. For the irrigation experiment, the north 25 of each group of 50 trees on the roto-cleared soil and the south 25 of each group of 50 trees on the dozer-cleared soil were left un-weeded. Exterior sides were selected for weeding to avoid disturbance of the soil sensors which had been located nearer to the middle of the study plot. For the natural sprouts growing on roto-cleared or dozer-cleared soil, half of the trees were randomly selected for weeding (2m weed-free area) while the other half remained un-weeded. All competing vegetation was removed mechanically, using a hoe or hand-held gasoline powered weed-eater. Weeded plots were maintained free of all vegetation except for the aspen tree all summer. This treatment allowed a comparison of the effects of weeding on tree growth and survival.

Natural sprouts were growing at random spacing, about 1 ft to 8 ft apart. Natural sprouts selected for measurement were thinned to no closer than 5 ft spacing. The potted and natural trees in all locations were from unknown genotypes, likely different from the irrigated study transplants. Treatments examined are as follows:

1. II-W mine, fenced site 1, transplanted aspen plants, roto-cleared/fresh topsoil, high irrigation

2. II-W mine, fenced site 1, transplanted aspen plants, roto-cleared/fresh topsoil, medium irrigation

3. II-W mine, fenced site 1, transplanted aspen plants, roto-cleared/fresh topsoil, no irrigation

4. II-W mine, fenced site 1, transplanted aspen plants, roto-cleared/fresh topsoil, low irrigation

5. II-W mine, fenced site 1, transplanted aspen plants, dozer-cleared/stored topsoil, medium irrigation

6. II-W mine, fenced site 1, transplanted aspen plants, dozer-cleared/stored topsoil, no irrigation

7. II-W mine, fenced site 1, transplanted aspen plants, dozer-cleared/stored topsoil, high irrigation

8. II-W mine, fenced site 1, transplanted aspen plants, dozer-cleared/stored topsoil, low irrigation

9. II-W mine, fenced site 1, root segment natural aspen sprouts, roto-cleared/fresh topsoil, no irrigation

10. II-W mine, fenced site 1, root segment natural aspen sprouts, dozer-cleared/stored topsoil, no irrigation

11. II-W mine, fenced site 2, planted potted aspen seedlings, dozer-cleared/stored topsoil, no irrigation

12. Yoast mine, non-fenced site, natural aspen sprouts

Treatment 12 was studied only in 2005. Most of the aspen plants in this unfenced treatment were severely damaged by ungulates, verifying the importance of fencing for aspen establishment. All data collected in 2006 were from fenced plots and do not reflect the devastating effect of browsing by wild ungulates without the benefit of fencing.

Data Collected:

Prior to bud break initial height of each tree and number of branches was recorded for each tree. Tree growth was measured periodically throughout the growing season. Physical measures of growth were total terminal and branch growth (cm), crown height (cm), basal caliper (mm), and number of basal sprouts (count). Water status of the trees was measured twice during the summer of 2006.

Water status, determined as leaf water potential of the plants, was measured as near to dawn as possible (½ hr predawn to ½ hr after sunup) to capture the minimum stress before rapid morning transpiration began depleting leaf moisture. Treatment, ambient temperature, time of sampling and exuding pressure level was recorded.

Leaves were collected from the different treatments at random to minimize time of sampling biases.

Leaf water potential will increase as water is withheld from the plant and plant water stress increases. Water status measurements required removing one fully matured leaf randomly selected from trees in each treatment and measured for water holding capacity using a Plant Water Status Console. The leaf was removed from the plant and immediately placed in a sealed chamber with the petiole extending through a sealing hole in the chamber. A fresh slightly angled cut was made and nitrogen gas was delivered to the leaf under slowly increasing pressure until water exudes from the petiole surface. The pressure necessary for this to occur is an indication of the leaf water potential or water holding capacity of the leaf, an indication of the water stress and thus physiological stress of the plant. Different plants from each treatment were selected at each testing to minimize leaf loss from sampling. From 2-3 total measurements were made from each treatment each day of measurement. Number of measurements depended on the time necessary for each measurement, so that all measurements fall within the dawn-time window. Each day of measurements included the full cycle of irrigation treatments. Size of sampled leaf was recorded as length from tip to petiole (mm), and maximum width (mm). An empirical equation was developed to relate width and length to actual leaf area.

Quality assurance/quality control procedures:

Measurements were made and recorded periodically throughout the growing season. Field staff that conducted growth and pressure measurements were trained on correct measuring protocols by R. Musselman, using instrumentation and measurement tools provided by the project. Field staff were instructed to contact R. Musselman by phone should questions arise regarding sampling measurements or protocols. Data collected in 2005 were recorded by hand on data sheets and transferred to excel files for analysis. Data were keyed directly into a field data processor in 2006 for transfer to excel files and analysis. Backups of field data sheets and original data files were archived. A field notebook documented events as they occurred throughout the season.

Results:

This study was conducted to demonstrate the effectiveness of supplemental irrigation on growth and survival of transplanted aspen sapling trees, but the experimental conditions allowed observation on several additional variables. In addition to irrigation (four levels of watering), we were able to observe growth and survival of aspen of different plant type (transplants, natural sprouts, and potted plants), soil type (roto-cleared/fresh and dozer-cleared/stored soil), and weed control (weeded and not-weeded). Since not all treatment combinations existed and none of the treatments were replicated, statistical analyses and inferences are limited. The differences for growth and survival discussed in this report are based on our observation of the dataset and not based on statistical analysis for significance of differences. Even if differences in growth or survival between treatments had been statistically verified, interacting treatment effects confound conclusions that can be drawn. For example, differences between natural sprouts on roto-cleared soil and transplants in irrigated treatments may be due to differences in soil disturbance, genetic stock of aspen, transplant type, or microclimatic differences between sites, treatments not independently replicated for this initial case study designed for this one location. Nevertheless, given all these caveats several observations are evident from the study that can be useful for future aspen management and to identify areas for additional research.

Irrigation:

Rainfall was well dispersed during the 2006 growing season, except for a 3-week period in June (Figure 3a); but soil moisture appeared to be adequate after spring snowmelt entering this June drought period. Temperatures were moderate during this time period (Figure 3b). Rainfall was different for the two monitoring stations (the experimental site, and near the entrance to the mine access road about 2 km west), but major rainy periods were similarly documented at both sites. For this experiment, there appeared to be an effect of irrigation treatment on soil moisture in the irrigated plots; but soil moisture decreased through the season, especially for non-irrigated controls

(Figures 4a). Weeded plots retained more soil moisture (Figure 4b). Highest soil moisture was in the high irrigation treatment, followed by the medium irrigation treatment, and both of these had higher soil moisture than the low and no irrigation treatments (Figures 4b, 5a, 5b), verifying the effectiveness of the irrigation treatments. However, there appeared to be no benefit to soil moisture over natural rainfall with the low irrigation treatment in the dozer-cleared/fresh soils (Figures 5a, 5b).

The dozer-cleared/stored soil was not as well drained, as evident by the apparent greater retention of water in these soils than in the roto-cleared soils (Figures 4a, 4b, 5a, 5b). This was also apparent from the accumulation of water in a soil pit downhill from the plot during periods of heavy rainfall vs no water accumulation in a similar pit downhill of the roto-cleared/fresh soil. This also appears to be confirmed by the higher soil moisture at deeper vs shallower depth in the dozer cleared soils, compared to the reverse relationship in the roto-cleared soils (Figure 5a, 5b). Non-irrigated dozer-cleared soil generally retained more moisture than non-irrigated roto-cleared soils (Figures 4a, 4b, 5a, 5b).

Aspen growth did not respond to irrigation as expected in either soil type. Growth seemed to be negatively related or un-related to the amount of water delivered to the plants, depending on the growth variable (Figures 6a, 7a, 8a, 9a, 10a). Survival was lower in those plots receiving the highest irrigation treatment (Figure 11a). It was observed after the first year of irrigation in 2005 that salt buildup was evident on the soil surface of the irrigated trees; and it appeared that salt on the soil surface seemed to be more obvious in the treatments with the highest amount of water added. The primary source of irrigation water during 2005 was the first main pond to the right of the road after entering the main road to the II-W mine from County Road 53, at the beginning of the S-curve, down slope from the experimental site, Sediment Pond 006 (see Pond on map, Figure 1). During the 2006 season, it was expected that water would be obtained from different sources than during 2005. Upon further investigation, it was determined that most of the water for irrigation during 2006 came from the same holding pond as during 2005, Sediment Pond 006 on the lower portion of the main road to the II-W mine. Total dissolved solids of water from this Sediment Pond 006 was 3722 mg/L in 2006

(data from Seneca Coal Company), equivalent to an electric conductivity (EC) of greater than 4 dS/m.

Electric conductivity (EC) measured from soil samples collected at the experimental site indicate that those soils with the highest irrigation treatment were the most saline (Figure 12), with an EC of > 3 dS/m for those plots receiving the highest amount of irrigation. It is known that aspen trees are sensitive to saline conditions. EC levels > 3 dS/m are considered saline. Our data confirm the findings of Van Cleve et al. (1993) and others who found that saline soil conditions inhibited the growth of aspen. The data suggest that care must be taken when deciding appropriate sources of water for irrigation of plantings on reclaimed mine lands. Salinity of irrigation water should be monitored before it is used.

Pre-dawn leaf water potential levels were only monitored on two occasions during 2006 and these data indicate moisture stress was generally less than 8 bars (0.8 mPa) pressure, and was not significantly different among irrigation treatments (data not shown). Moisture was sufficient during most of the 2006 growing season that even the non-irrigated controls did not seem to experience water stress conditions. However, there were likely times during the season when moisture stress apparently limited growth of aspen (see weeding treatment discussion below), but unfortunately we were unable to schedule leaf water potential measurements during those times when rainfall was limited.

Plant type:

The aspen saplings used in the irrigation study that were transplanted from the Yoast site exhibited considerably more injury and had considerably more disease infections than natural sprouts arising from buried root segments or potted plants in 2005, the first year after transplanting. However, the trees that recovered and survived into 2006 showed little injury and disease during the second (2006) growing season (data not shown). There were a larger number of branches (Figure 8b) and more basal sprouts (data not shown) on natural sprout trees than on transplanted or potted trees. Potted trees generally grew as well as transplanted trees; but potted trees grew less than natural sprouts (Figures 6b, 8b, 9b), except for crown height (Figure 10b). Basal

caliper growth of potted trees, natural trees on fresh soil, and irrigated trees on stored soil were similar (Figures 7a, 7b). Best basal caliper diameter growth was on low irrigation or non-irrigated weeded trees on roto-cleared/fresh soil and on weeded natural sprouts on dozer-cleared/stored soil (Figures 7a, 7b). Survival was different by plant type, and was particularly influenced by weeding for natural sprouts (Figures 11a, 11b).

Soil type:

Roto-tilled/fresh soil provided sufficient natural sprouting during 2005 to provide an adequate stand of aspen trees, and these trees (when weeded, see below) grew better and survival was higher than adjacent transplanted trees growing in the same soil. Dozer-cleared/stored soil had considerably lower numbers of natural sprouts than roto-cleared/fresh soil, and stocking was sparse (data not shown). Average leader growth was higher for natural sprouts on dozer-cleared/stored soil than irrigated trees on the same soil (Figures 6a, 6b), but crown height was similar (Figures 10a, 10b). Leader growth (Figure 6a), basal caliper (Figure 7a), crown height (Figure 10a), and survival (Figure 11a) of trees were considerably less on dozer-cleared/stored soil than on roto-cleared/fresh soils for the irrigation experiment. These differences cannot be attributed to salinity, since EC of both soils responded similarly to irrigation with the highest EC occurring under the highest irrigation treatments (Figure 12). Whether the growth difference is due to soil type, the storage of the soil before placement at the site, or any compaction/drainage differences of the two soil types is unknown.

Other than higher EC and pH in irrigated soils, soil chemistry analyses appeared to show no large differences that might be attributed to irrigation treatment or soil type (Figures 13-21). Perhaps most noticeable was the higher potassium and zinc in the undisturbed aspen stand soils. Soils examined in this study were not sodic (SAR >12, data not shown). Soil chemical analyses reported soil texture estimates for all soils as loam. Actual percent sand/silt/clay analyses were not performed.

Weed control:

Weed control during 2006 had a major influence on growth and survival of aspen. Soil moisture was higher in the weeded plots (Figures 4b, 5a, 5b), suggesting more

water was available to the aspen trees for growth when trees were weeded. Soil moisture was somewhat higher at 20 cm depth than 40 cm depth for roto-cleared/fresh soils compared to higher moisture at the greater depth for dozer-cleared/stored soils (Figures 5a, 5b), perhaps suggesting poorer drainage of the dozer-cleared/stored soil type.

Trees that were weeded generally had greater leader growth and higher basal caliper growth than un-weeded trees for the irrigation experiments (Figures 6a, 7a), particularly on the roto-cleared/fresh soils. Growth differences were not as evident for number of branches, caliper at the base of the crown, and crown height (Figures 8a, 9a, 10a). Survival differences in the irrigation experiment was related to the amount of water delivered to the plants (Figure 11a), and the highest salinity was in the highest irrigation treatments (Figure 12).

Natural sprouts on roto-cleared/fresh responded dramatically to weeding, with growth generally higher in weeded plots (Figures 7b, 8b, 9b, 10b). Survival of un-weeded trees on the roto-cleared/fresh soil type was very low, while all weeded trees survived (Figure 11b). Differences in growth of weeded and un-weeded on the dozer-cleared/stored soil were less obvious, except for the much better basal caliper growth for weeded trees (Figure 7b). As with the roto-cleared/fresh soil, all of the trees that died on the dozer-cleared/stored soil were un-weeded. Growth of potted plants was generally less than natural sprouts and more similar to irrigated trees. Survival of potted plants was high.

An interesting finding was observed in the non-irrigated plots where all of the weeded trees survived while many of the non-weeded trees, particularly those on the roto-cleared/fresh soil, lost their leaves prematurely and appeared to have died (Figure 11b). Leaves on these trees appeared to be green and wilted before dropping, rather than yellow as a sign of early senescence. Whether these apparently dead trees survive from residual live buds and/or roots will be determined in 2007. However, it appears that removing weed competition to insure adequate soil moisture improves the survival of aspen.

Conclusions:

1. A clear finding from the 2005 field study verified that fencing is important for adequate survival and growth of aspen by preventing wild ungulate grazing.

2. The importance of irrigation in aspen establishment is uncertain given the adequate natural rainfall the first two years of this experiment and the conflicting adverse effect of saline irrigation supply water. Some growth parameters and survival of aspen were inversely related to the amount of supplemental irrigation, likely a consequence of the high salinity of the irrigation water.

3. Initial findings of this study suggest that the best opportunity to obtain aspen reproduction on reclaimed surface-minded lands is by using fresh roto-cleared top soil from original aspen stands to obtain sufficient natural root sprouts. Fresh dozer-cleared soil may also provide sufficient root sprouting, but we were not able to examine that possibility in this study.

4. Weeding appears to enhance growth and survival of aspen, suggesting weed competition for available soil moisture. Available soil moisture was higher in weeded plots, and these trees generally grew better and had higher rates of survival.

5. Transplanted sprouts, regardless of irrigation treatment, showed considerable transplant injury during 2005, but little additional injury or mortality was evident during 2006. Planted aspen requires additional number of plants for survival and additional time for recovery from transplant shock.

6. Potted aspen from nursery stock with a small amount of weed block fabric grew well on dozer-cleared/stored soil without irrigation during these two years with adequate rainfall.

Application of research results:

This study was designed to provide information to compare survival, growth, and water status of irrigated aspen saplings at a single site on the Seneca Coal Mine, Hayden, Colorado. The study also compared survival, growth, and water status of transplanted aspen with planted potted nursery-grown stock and with natural sprouts. Application of study findings is limited to the study site, but should be useful to provide information for the design of future replicated experiments for determining specifics of irrigation treatment required for survival of aspen sprouts. Important in application of

these results is insuring that irrigation supply water for future plantings has low salinity. The study also found that potted nursery-grown stock with weed block grew well even when un-irrigated. The importance of preventing weed competition in future aspen restoration projects was well documented in this study. Continuing and proposed studies will verify these initial observations.

2007 Research Plan:

Growth of transplanted plants in third year: In a study funded by the DOI OSM, we will examine the survival and growth of aspen trees in their third season after transplanting to reclaimed roto-cleared and dozer-cleared top soils. Growth of the surviving trees will be monitored during their third year following transplanting. Care will be taken to insure low salinity of the irrigation water supply. RMRS will coordinate with Seneca Coal Company regarding adequate supply of low-saline water.

Root growth: Survival and growth of individual aspen plants is only a part of successful re-establishment of the species on reclaimed lands. The re-establishment of the extensive lateral root systems that existed in clones that were previously on these sites is crucial to the long-term persistence of aspen on these sites. The density of aspen sprout populations naturally decline over time (Shepperd 1993). Therefore it is imperative that newly planted aspen begin to expand their roots systems so that they might establish new sprouts if the planted trees die. We will quantify the growth and spread of lateral root systems from planted aspen by excavating and washing soil from the roots of selected trees to quantify root growth under the different irrigation, soil type, and plant type treatments. Given known mortality rates of young aspen (Shepperd 1993) subsequent root development and suckering will be necessary for aspen to be sustained and successfully re-established on these reclaimed mine sites. It is particularly crucial to see if roots have extended beyond the planting hole for transplants or beyond the potting mix for potted aspen. If lateral root development is detected, then experiments to stimulate additional suckering could be conducted to investigate ways to expand the number of aspen stems on these sites. We will continue to monitor soil physical and chemical characteristics for this experimental site. We will quantify soil

density and compaction effects on root growth and expansion in the irrigated transplanted trees. We will conduct analyses of soil texture and bulk density.

Physiological status: Although monitoring of leaf water potential gave an initial indication of water stress condition of the plants under specific irrigation schedules, additional physiological conditions of the plant vital to survival are unknown. Other physiological conditions, such as stomatal conductance, photosynthesis, and respiration, may show response to drought prior to indication by plant water status. Therefore, monitoring during 2007 will include additional physiological measurements of the transplants under each irrigation treatment, including photosynthesis, respiration, and transpiration. This should allow a better evaluation of the physiological stress conditions occurring under specific irrigation treatments; and the physiological conditions favorable for survival. We will expand the monitoring of physiological stresses by conducting more frequent physiological measurements on aspen transplants, sprouts from root segments, and potted plants to gain a better understanding of the factors that are likely to affect long-term aspen establishment and survival. Given additional resources, we could expand these studies to examine the physiological stresses of other species such as willow and other shrubs that are also being planted in mine reclamation activities, to help gage their suitability for survival on reclaimed lands.

Proposed Future Research:

In response to the success of the weeding treatments on growth and survival of aspen during the 2006 growing season, we propose to initiate a new experiment during the 2007 and/or 2008 growing seasons. Aspen growing stock would be planted using standard weed control fabric and machine planting as recommend by the Colorado State Forest Nursery. The experiment would plant aspen in several fenced areas on the Seneca mine, with or without the weed barrier fabric. Irrigation water would also be examined. One-third of the planted aspen would receive pond water by drip system or by periodic watering from bulk tank as needed. Another third would receive water verified with low EC, and the last third would receive no supplemental irrigation water. Given the compaction and high density of the reclaimed soils, another treatment worth

examining would be deep cultivation subsoil trenching using 'sod-busting' chisel plow equipment prior to planting. This would break up the compacted soils and allow deeper penetration of root systems to enhance survival the first few years after planting. We propose to plant these nursery stock aspen during the summer of 2007, and follow their physiology, growth, survival, and establishment through at least three growing seasons. The experimental design for this fully replicated experiment would be an analysis of variance (ANOVA) with sources of variation treatments consisting of weed block (fabric or no fabric); trenching (subsoil trenching or no trenching); and irrigation (supplement rainfall with local pond water, low EC water, or no supplemental irrigation). The experiment would be replicated in 6 or more reclaimed fenced areas on the Seneca II-W mine. A full proposal and study plan would be written should interest be shown in this project.

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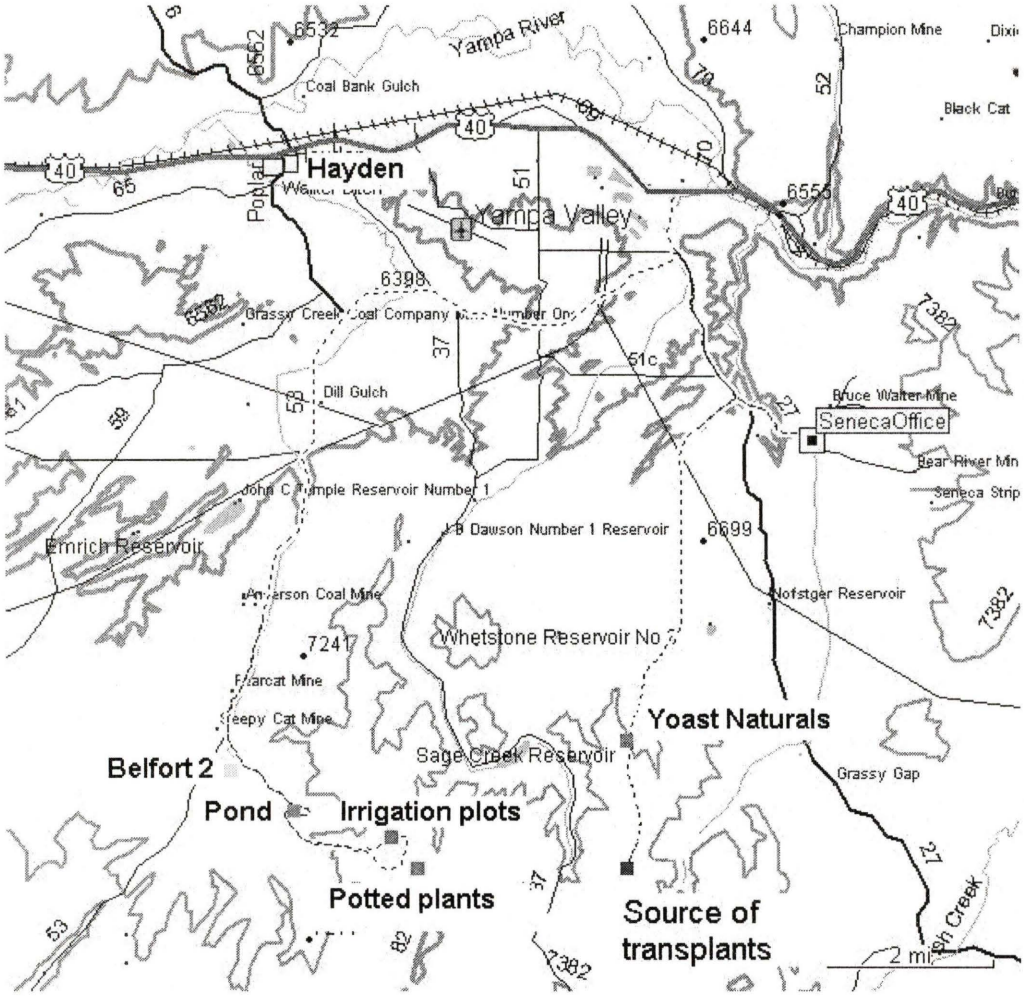

Figure 1. Map of Seneca Mine showing the location of the aspen reclamation experiment, including the II-W aspen irrigation experimental plots, potted aspen site, source of transplants for irrigation study, unfenced Yoast natural sprouts, irrigation water supply pond, and Belfort 2 rain gauge.

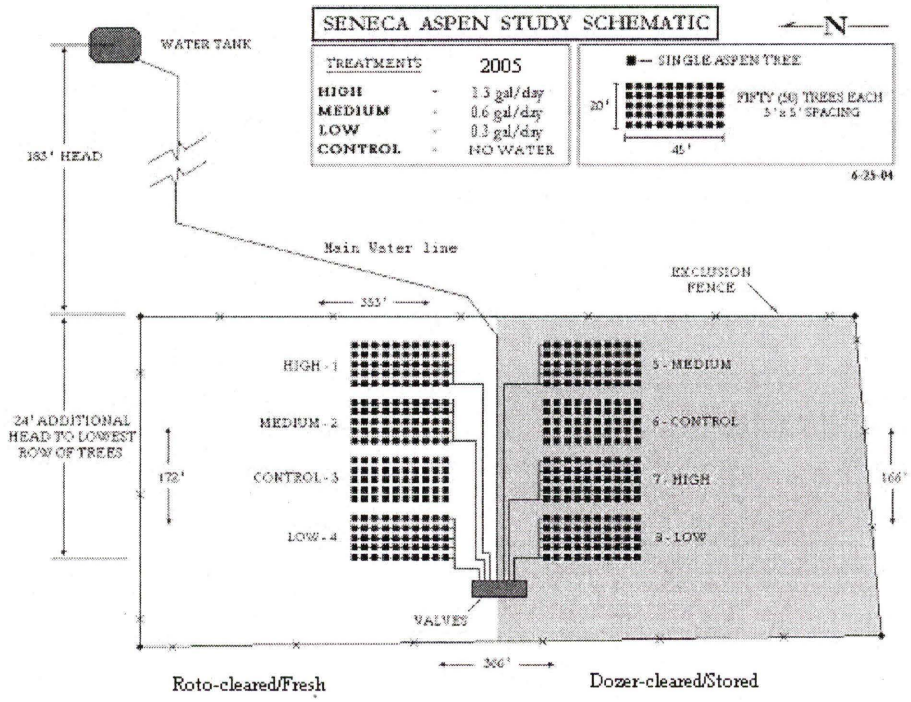

Figure 2. Original plot layout, Seneca aspen irrigation study. Roto-cleared/fresh soil was moved directly to the site from its source. Dozer-cleared/stored soil appeared to be stored for some time before placement.

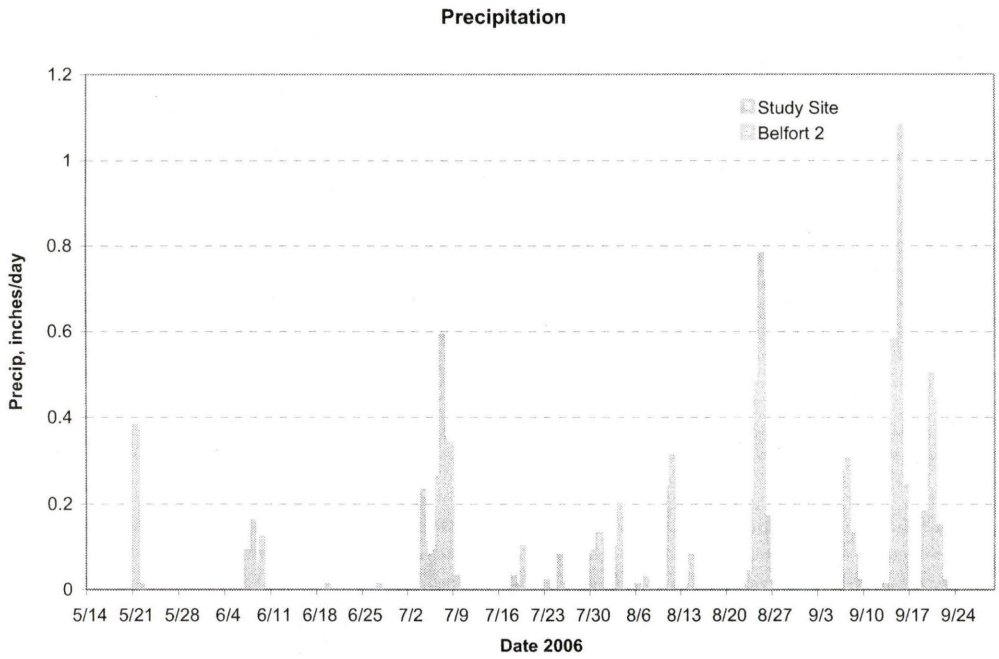

Figure 3a. Precipitation during the 2006 growing season at the Seneca aspen irrigation experiment site (blue) and at the Seneca monitoring station down slope from the experiment site (red).

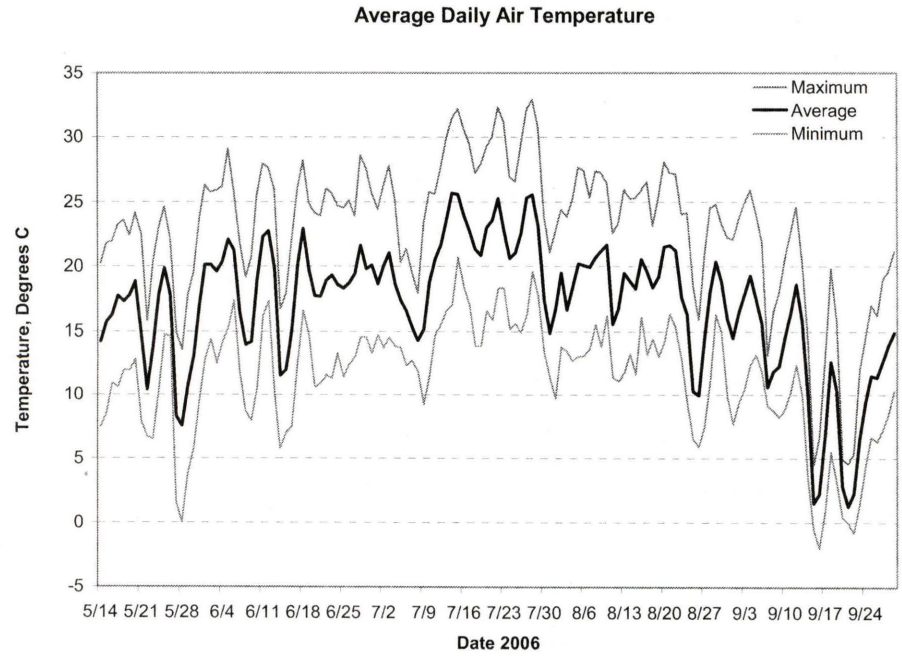

Figure 3b. Temperature during the 2006 growing season at the Seneca aspen irrigation experiment site.

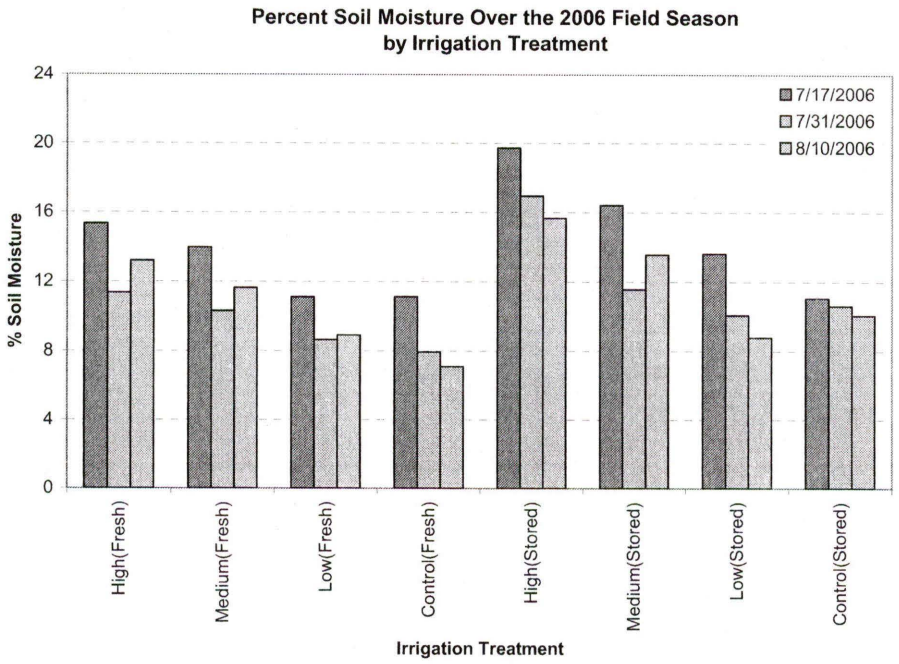

Figure 4a. Soil moisture at the Seneca aspen irrigation site. Irrigation levels were 0.65, 0.3, 0.15, and 0.0 gal/day/tree for the high, medium, low, and control irrigation treatment levels.

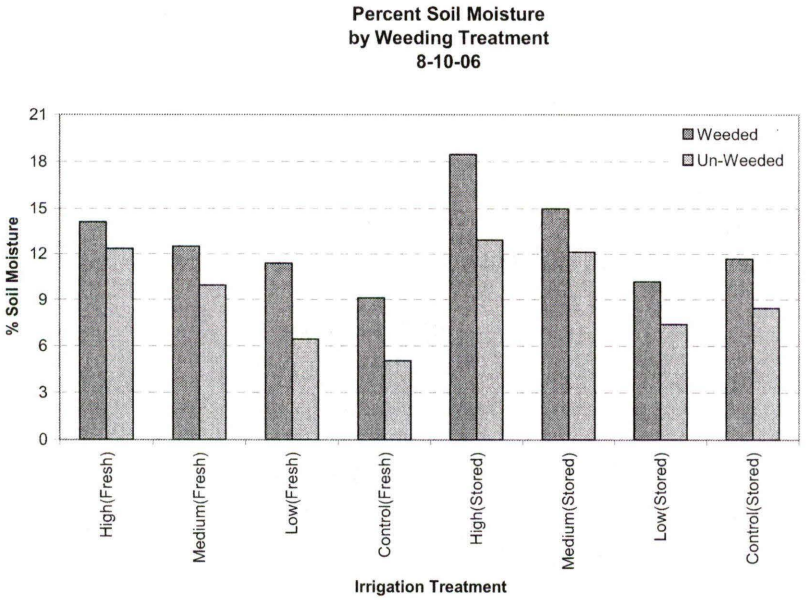

Figure 4b. Soil moisture by weeding treatment.

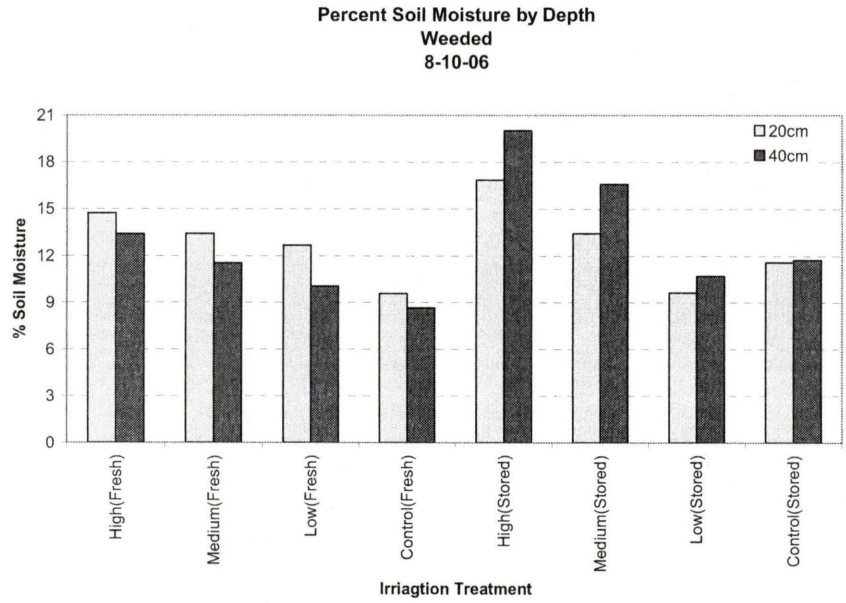

Figure 5a. Soil moisture of irrigated plots at 20 and 40 cm depth, weeded soil.

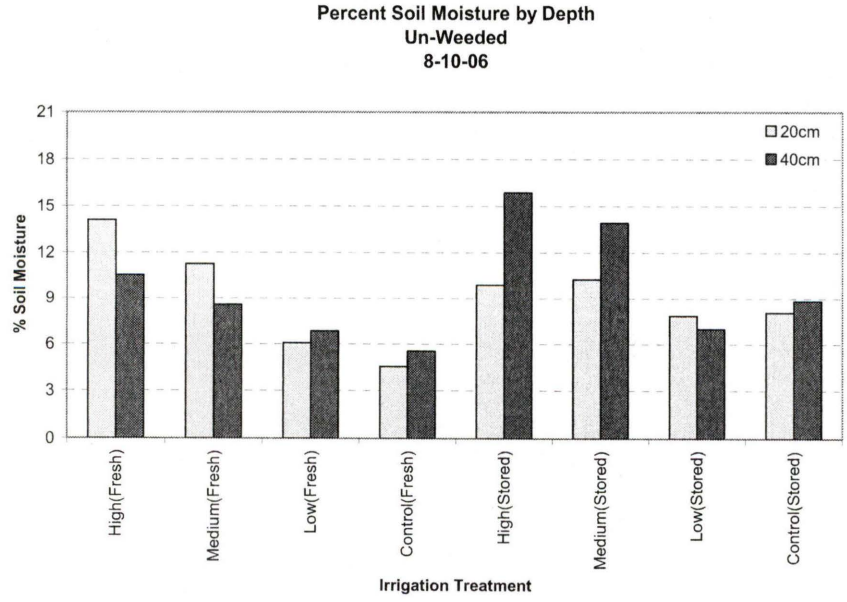

Figure 5b. Soil moisture of irrigated plots at 20 and 40 cm depth, un-weeded soil.

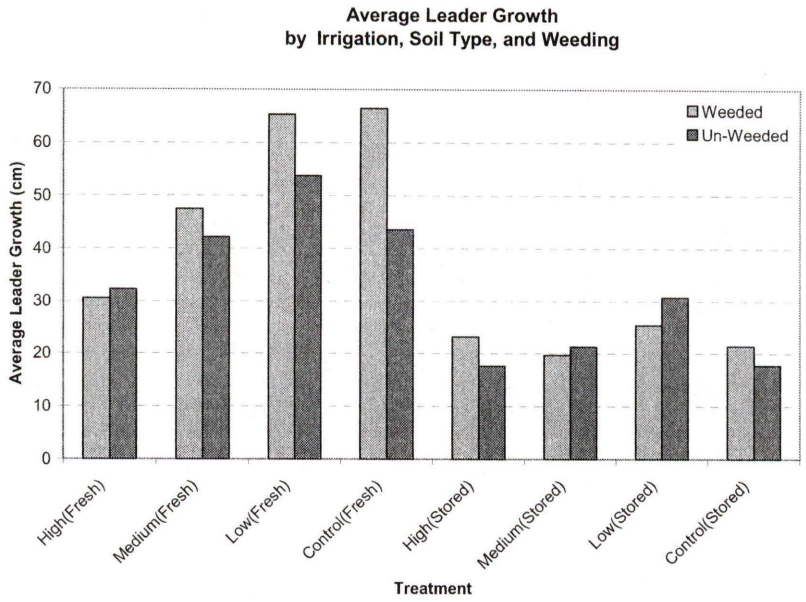

Figure 6a. Leader growth of aspen trees on irrigated plots, roto-cleared/fresh or dozer-cleared/stored soils, weeded or un-weeded. Irrigation levels were 0.65, 0.3, 0.15, or 0.0 gal/day/tree for the high, medium, low, and control.

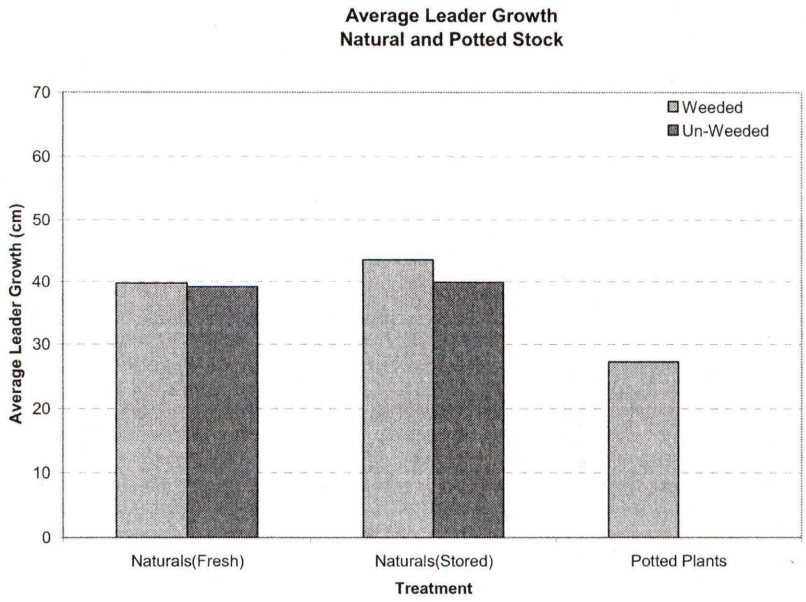

Figure 6b. Leader growth of potted aspen and natural aspen sprouts on roto-cleared/fresh and dozer-cleared/stored soils, weeded and un-weeded. Potted plants had a small piece of weed fabric around each plant, so they are plotted here as weeded. There were no un-weeded potted plants.

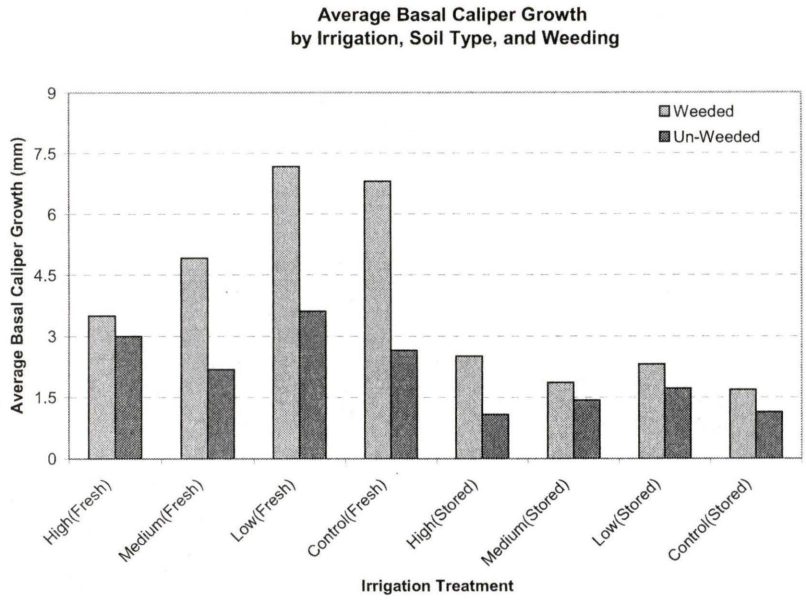

Figure 7a. Basal caliper growth of aspen trees on irrigated plots, roto-cleared/fresh or dozer-cleared/stored soils, weeded or un-weeded. Irrigation levels were 0.65, 0.3, 0.15, or 0.0 gal/day/tree for the high, medium, low, and control.

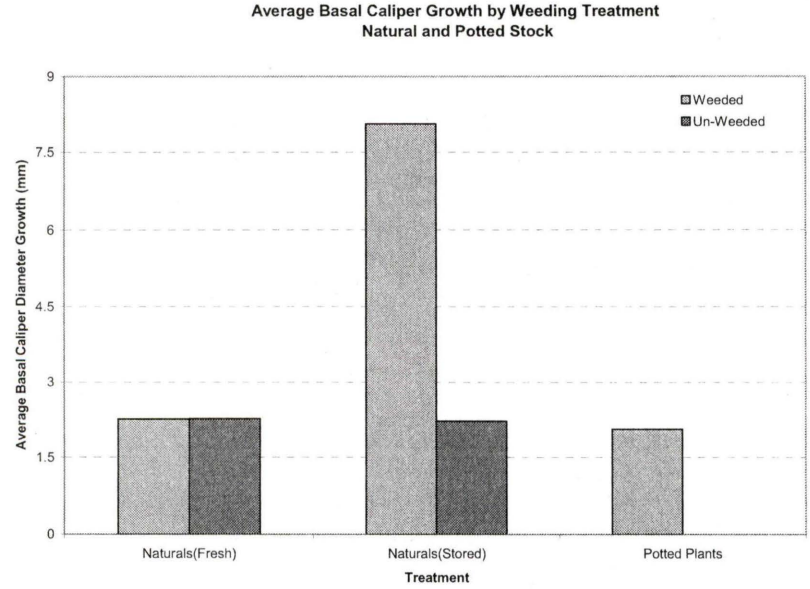

Figure 7b. Basal caliper growth of potted aspen and natural aspen sprouts on roto-cleared/fresh and dozer-cleared/stored soils, weeded and un-weeded. Potted plants had a small piece of weed fabric around each plant, so they are plotted here as weeded. There were no un-weeded potted plants.

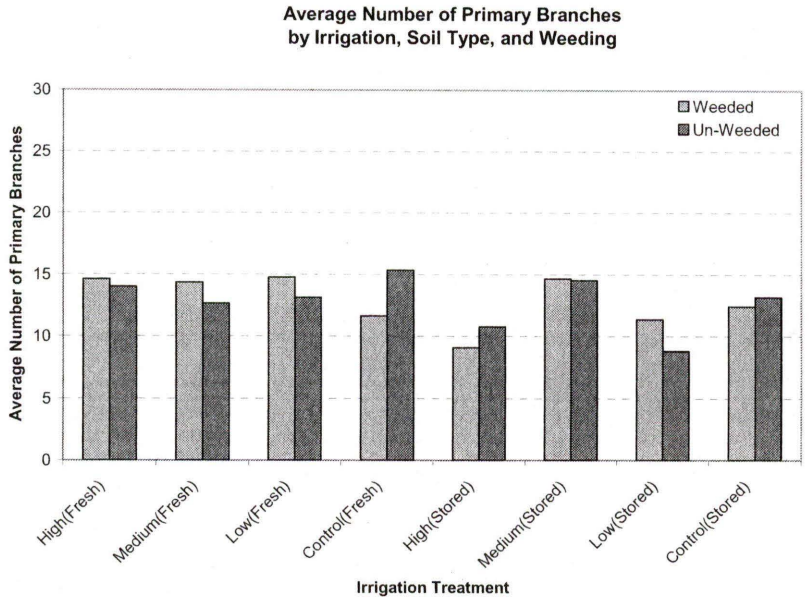

Figure 8a. Number of primary branches of aspen trees on irrigated plots, roto-cleared/fresh or dozer-cleared/stored soils, weeded or un-weeded. Irrigation levels were 0.65, 0.3, 0.15, or 0.0 gal/day/tree for the high, medium, low, and control.

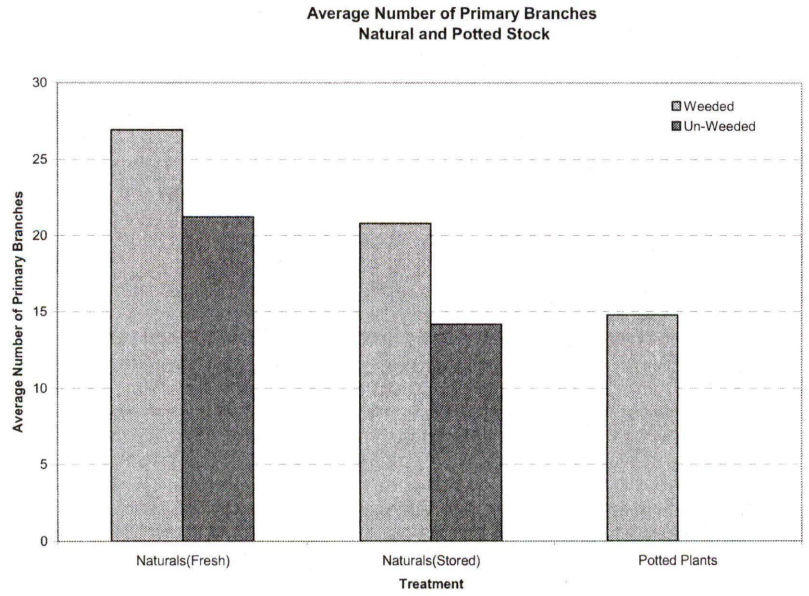

Figure 8b. Number of primary branches of potted aspen and natural aspen sprouts on roto-cleared/fresh and dozer-cleared/stored soils, weeded and un-weeded. Potted plants had a small piece of weed fabric around each plant, so they are plotted here as weeded. There were no un-weeded potted plants.

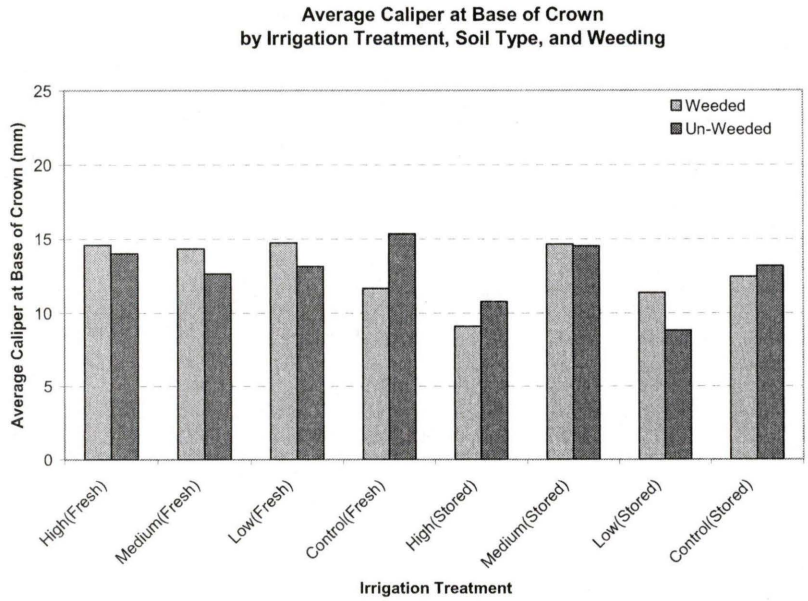

Figure 9a. Caliper at the base of the crown of aspen trees on irrigated plots, roto-cleared/fresh or dozer-cleared/stored soils, weeded or un-weeded. Irrigation levels were 0.65, 0.3, 0.15, or 0.0 gal/day/tree for the high, medium, low, and control.

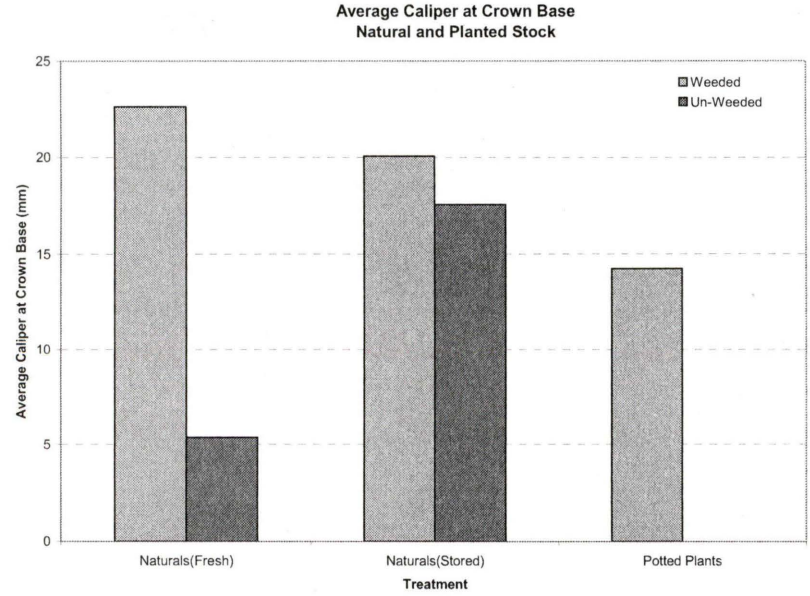

Figure 9b. Caliper at base of crown of potted aspen and natural aspen sprouts on roto-cleared/fresh and dozer-cleared/stored soils, weeded and un-weeded. Potted plants had a small piece of weed fabric around each plant, so they are plotted here as weeded. There were no un-weeded potted plants.

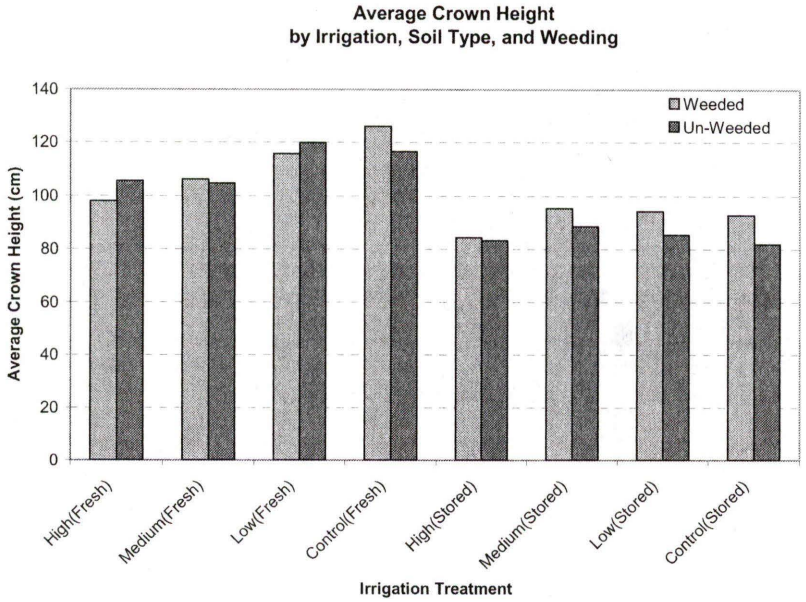

Figure 10a. Crown height growth of aspen trees on irrigated plots, roto-cleared/fresh or dozer-cleared/stored soils, weeded or un-weeded. Irrigation levels were 0.65, 0.3, 0.15, or 0.0 gal/day/tree for the high, medium, low, and control.

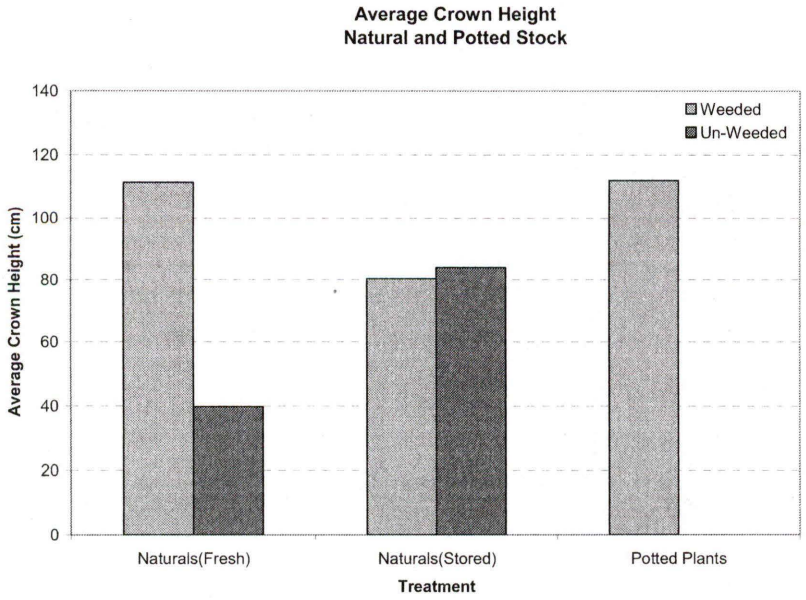

Figure 10b. Crown height of potted aspen and natural aspen sprouts on roto-cleared/fresh and dozer-cleared/stored soils, weeded and un-weeded. Potted plants had a small piece of weed fabric around each plant, so they are plotted here as weeded. There were no un-weeded potted plants.

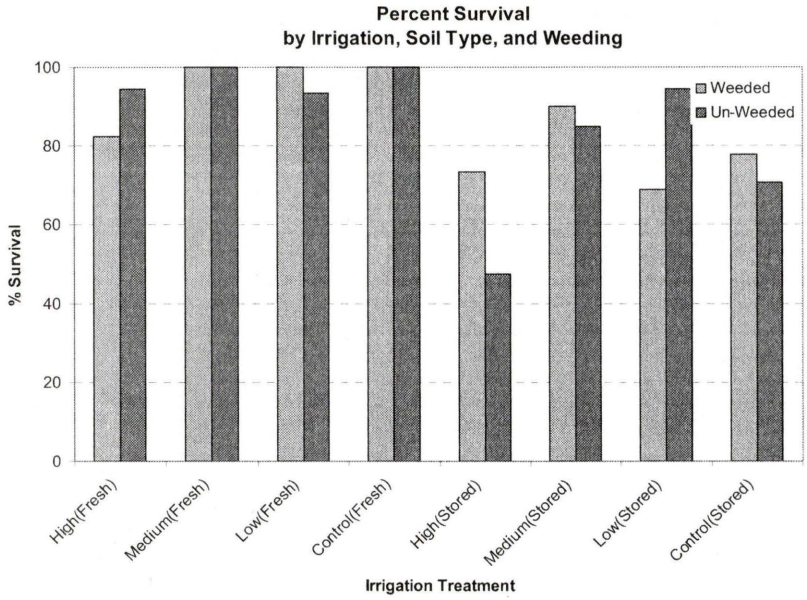

Figure 11a. Survival of aspen trees on irrigated plots, roto-cleared/fresh or dozer-cleared/stored soils, weeded or un-weeded. Irrigation levels were 0.65, 0.3, 0.15, or 0.0 gal/day/tree for the high, medium, low, and control.

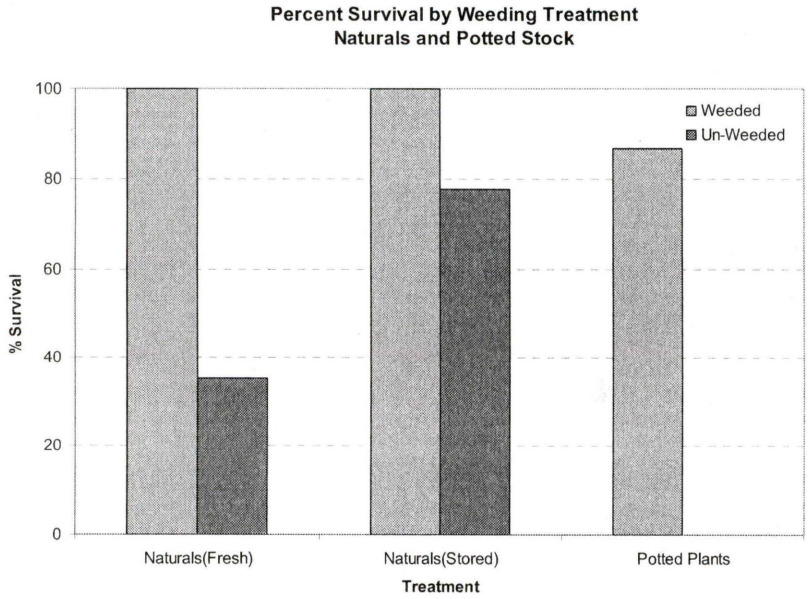

Figure 11b. Survival of potted aspen and natural aspen sprouts on roto-cleared/fresh and dozer-cleared/stored soils, weeded and un-weeded. Potted plants had a small piece of weed fabric around each plant, so they are plotted here as weeded. There were no un-weeded potted plants. All weeded natural sprouts survived.

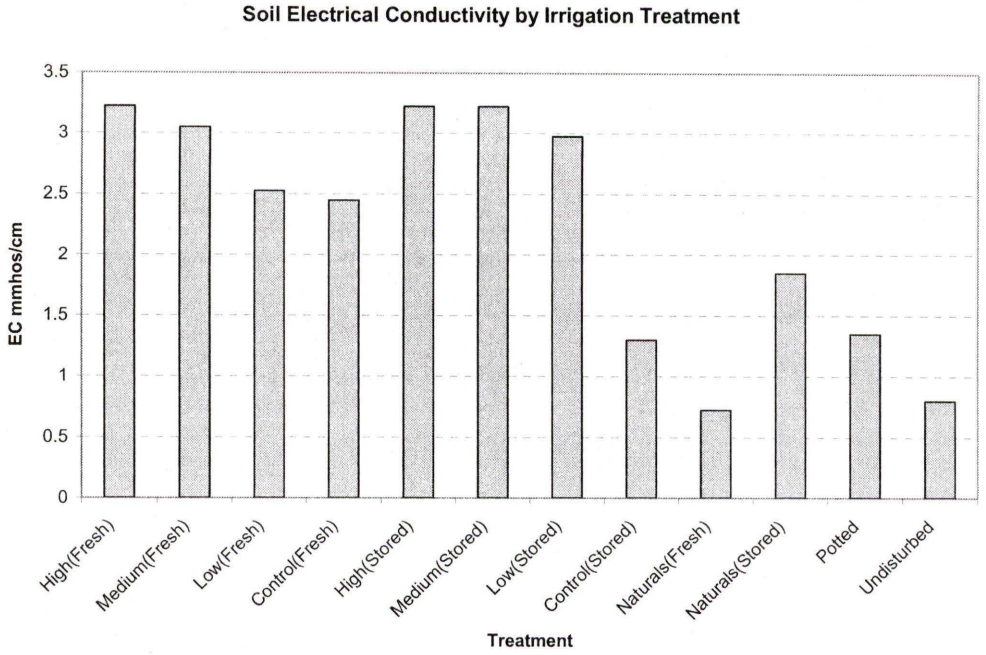

Figure 12. Electrical Conductivity of soils for aspen irrigation experiment, 2006.

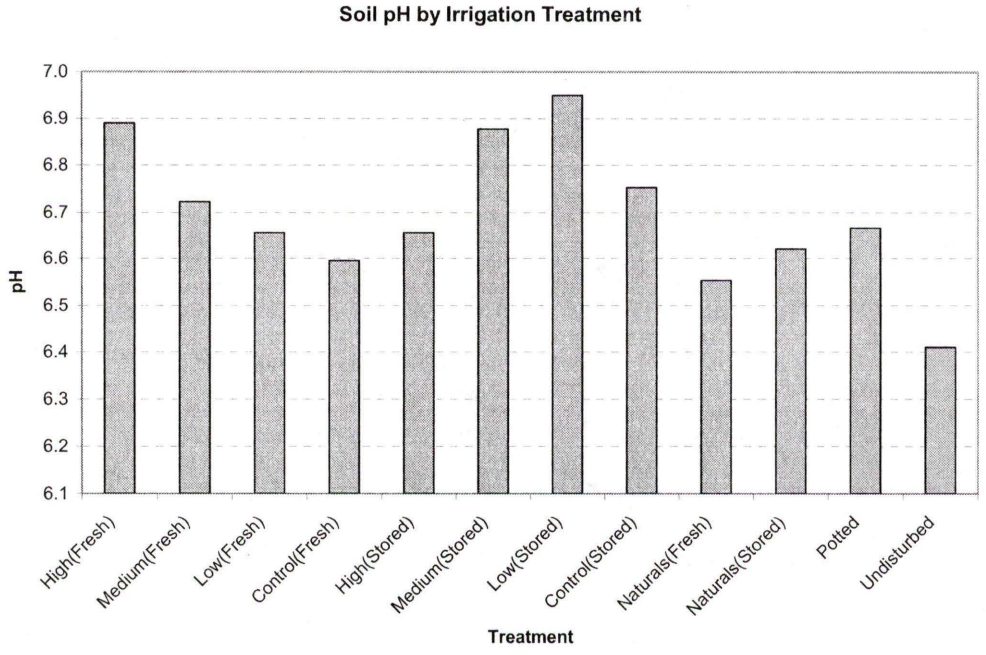

Figure 13. Soil pH for aspen irrigation experiment, 2006.

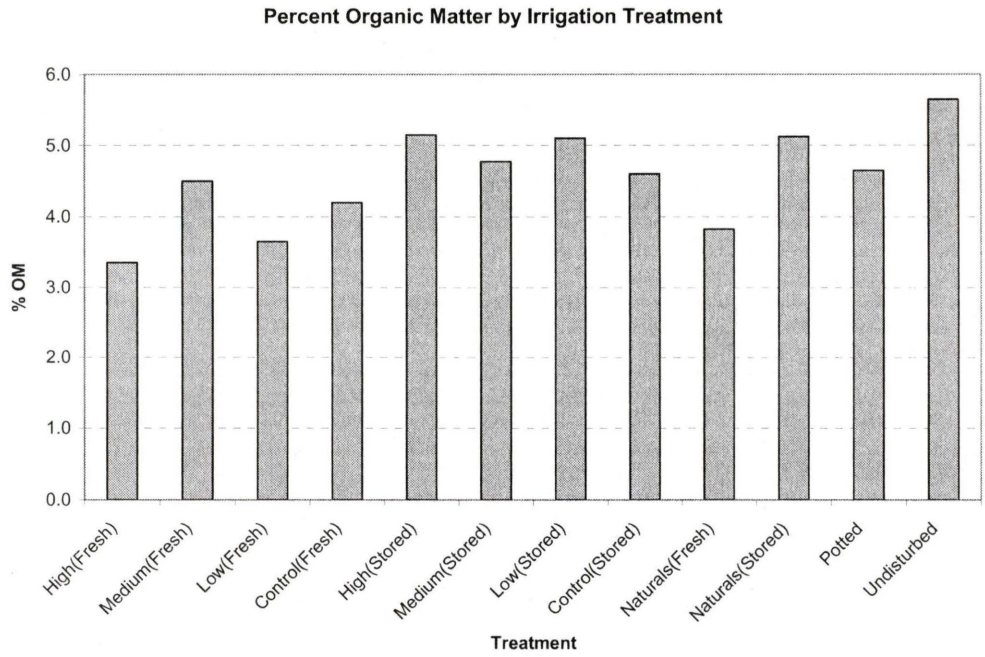

Figure 14. Soil organic matter for aspen irrigation experiment, 2006.

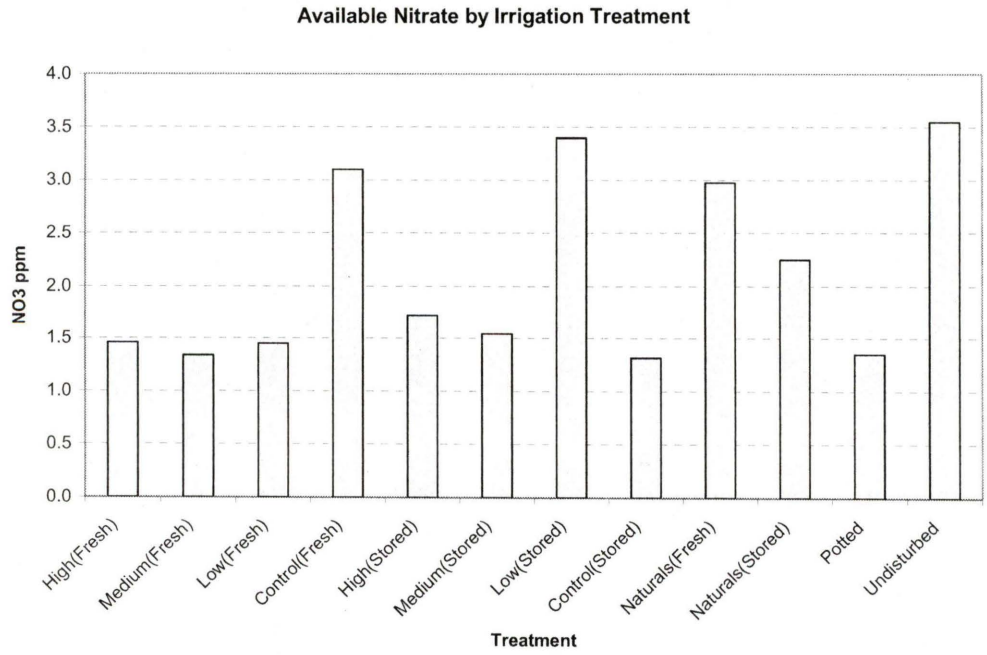

Figure 15. Soil nitrate for aspen irrigation experiment, 2006.

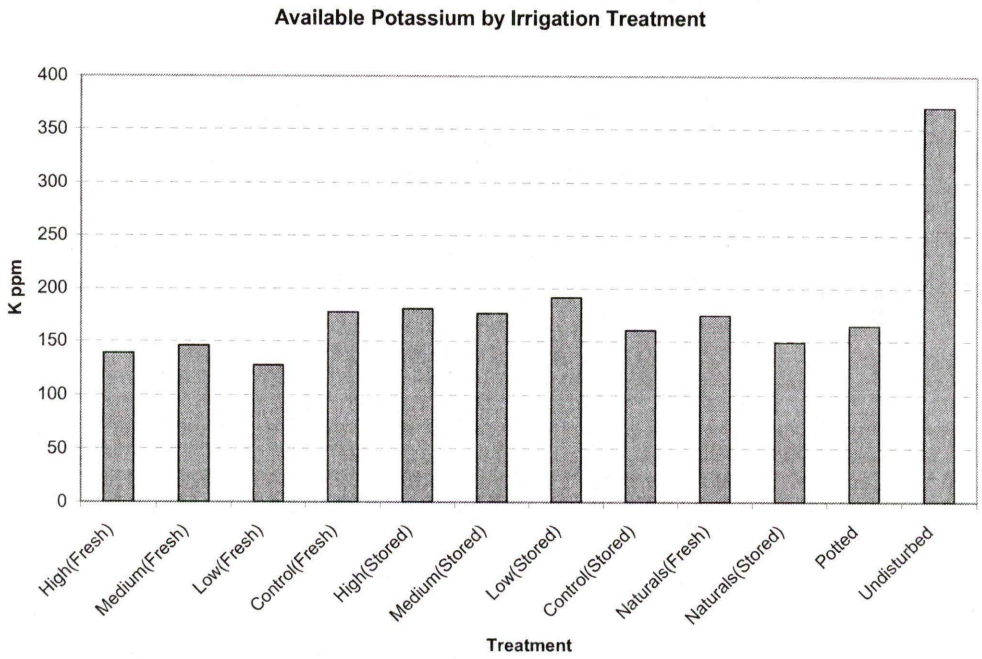

Figure 16. Soil potassium for aspen irrigation experiment, 2006.

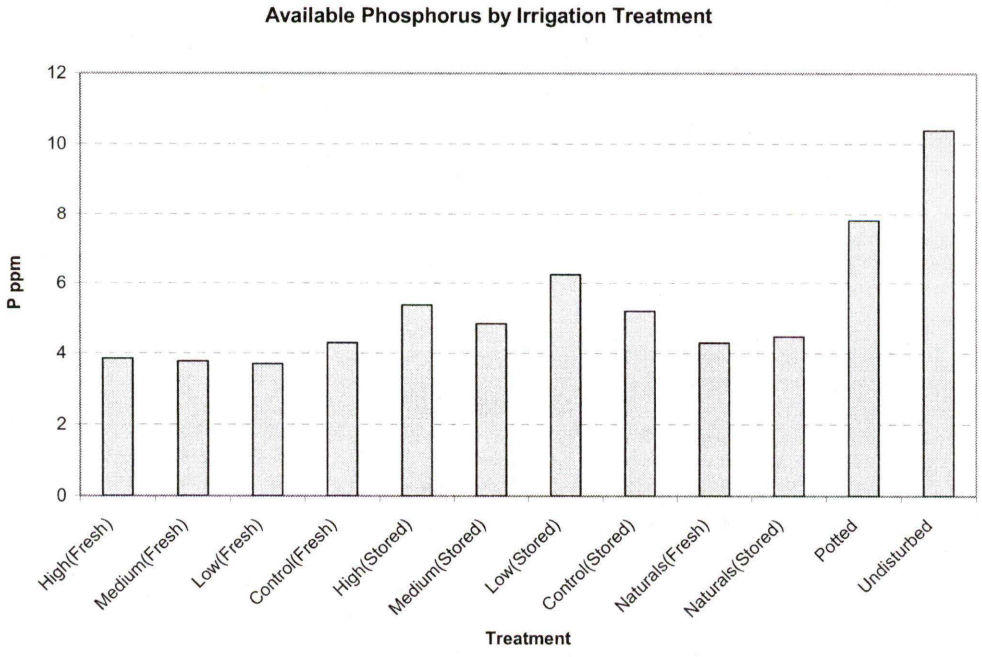

Figure 17. Soil phosphorus for aspen irrigation experiment, 2006.

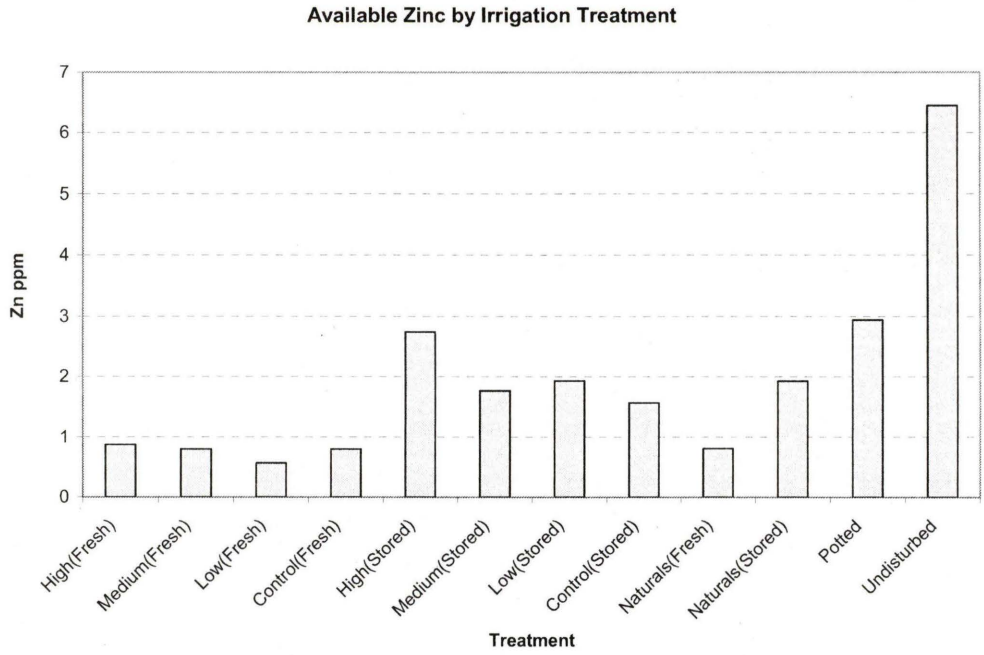

Figure 18. Soil zinc for aspen irrigation experiment, 2006.

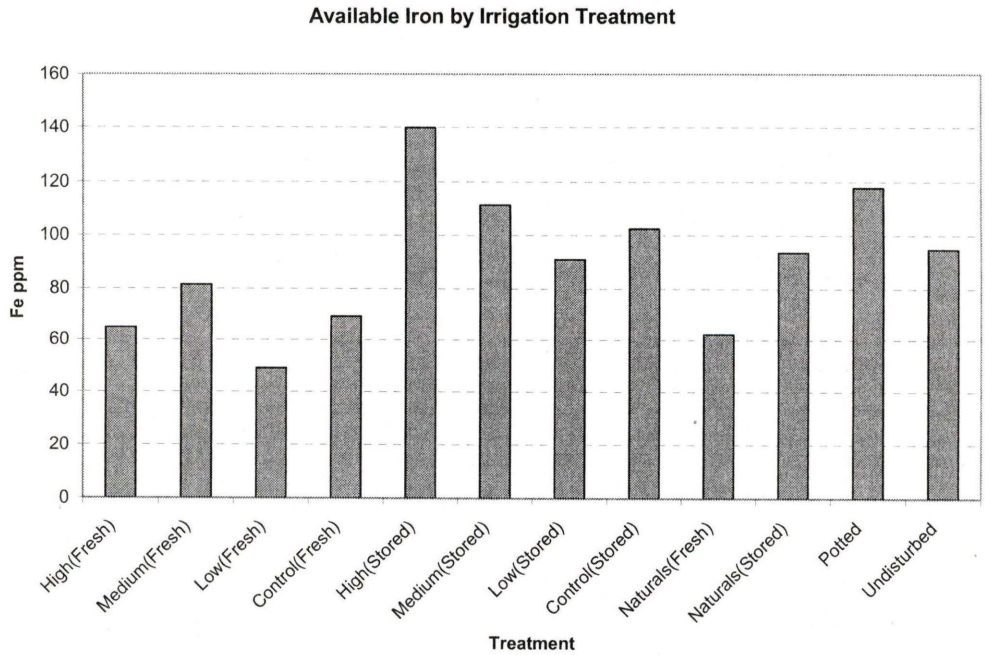

Figure 19. Soil iron for aspen irrigation experiment, 2006.

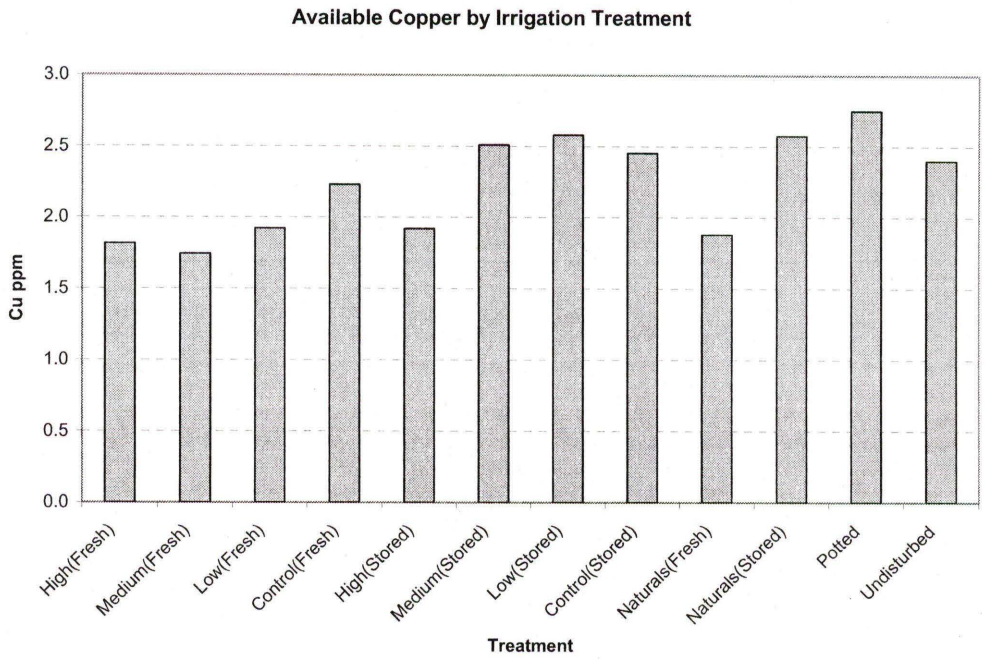

Figure 20. Soil copper for aspen irrigation experiment, 2006.

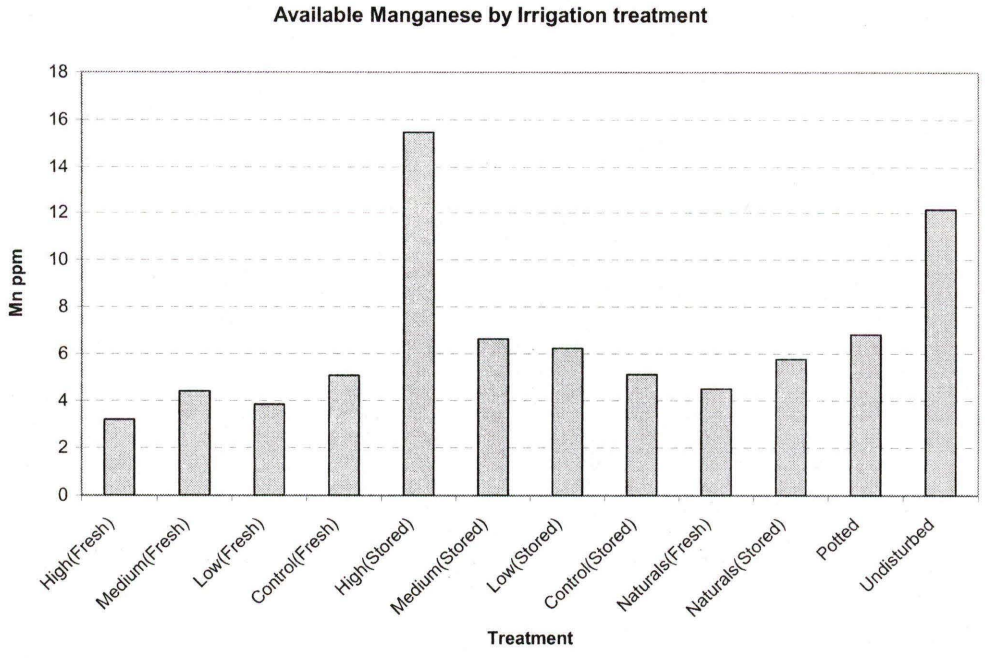

Figure 21. Soil manganese for aspen irrigation experiment, 2006.